Space Habitats

Patrick H. Stakem

Table of Contents

Introduction

This book covers the topic of Space habitats, places to live and work off-planet. We will discuss habitats in orbit, as well as those that might be used on the Moon, and Mars. Even though they fit the definition, we will not include crewed spacecraft. That category is more about transportation.

Author

The author received a Bachelors degree in Electrical Engineering from Carnegie-Mellon University, and Masters Degrees in Physics and Computer Science from the Johns Hopkins University.

He was glued to the black & white TV for the launch of the Vanguard, the U. S.'s first satellite, through the Apollo missions.

He began his career in Aerospace with Fairchild Industries on the ATS-6 (Applications Technology Satellite-6), program, a communication satellite that developed much of the technology for the TDRSS (Tracking and Data Relay Satellite System). At Fairchild, Mr. Stakem made the amazing discovery that computers were put onboard the spacecraft. He quickly made himself the expert on their support. He followed the ATS-6 Program through its operation phase, and worked on other projects at NASA's Goddard Space Flight Center including the Hubble Space Telescope, the International Ultraviolet Explorer (IUE), the Solar Maximum Mission (SMM), some of the Landsat missions, and others. He was posted to NASA's Jet Propulsion Laboratory for the MARS-Jupiter-Saturn (MJS-77), which later became the Voyager mission. It is still operating and returning data from outside the solar system at this writing.

The author has been at almost all of the facilities and launch sites discussed, in an official capacity. There is always time to slip away and visit the museums.

Mr. Stakem was affiliated with the Whiting School of Engineering of the Johns Hopkins University. He received NASA's Space Shuttle Program Managers commendation award, as well as two NASA Group Achievement awards, the NASA Apollo-Soyuz Test Program Award, and a Certificate of Appreciation, NASA Earth Science Technology Office. Mr. Stakem has completed over 42 NASA Certification Courses in various areas

Crewed Space Stations

There have been a series of Space Stations by the U.S., Russia, and China over the years, culminating in the currently operating International Space Station. These were primarily crewed science platforms, but did include habitats and facility's for the crew.

von Braun and Ley advocated a rotating torus for a Mars mission. With a diameter of 76 meters, if the wheel rotated at 3 rpm, the crew would experience 1/3 g. Author Arthur C. Clarke used a rotating space station in his novel, 2001: A Space Odyssey. In 1975, a NASA study at Sanford University came up with the Stanford Torus, a 1.8 km diameter habitat for 10,000 persons in orbit, rotating at 1 rpm. It was to be located at the Earth-Moon L1 Lagrangian point, where the gravity from the two bodies cancel each other.

This facility would revolve around a central axis, and provide a level of gravity to the inhabitants based on the centripetal force of rotation. You can simulate Earth surface weight, but would probably just go with enough simulated gravity to feel comfortable and keep things in place. At the time, there was no data on whether humans could function in a zero-gravity environment. Now that we know we can, the space station designs can be more functional. Von Braun had envisioned a 250 foot diameter torus that rotated, providing near Earth gravity. He also anticipated a fleet of Shuttles for construction in orbit. He saw the facility as a jump-off point for lunar and orbital technologys missions. We now know from experience that astronauts operate perfectly well in zero-G.

Lessons Learned from similar Earth-based facilities

As we go further from Earth, the mission duration's will increase, and the crew will begin to feel more isolated. That has been observed in similar terrestrial scenarios such as nuclear submarines, arctic, and antarctic bases.

A nuclear submarine can stay submerged for months, with limited communications, because that can give away its position. Crews are trained to operate efficiency in that environment of isolation. Similarly, outposts in Antarctica and drifting ice stations at the North Pole have similar problems, but with more open communications. The research stations in Antarctica are mostly shut down over the winter, with only a small maintenance crew. This has lead to a condition called “winter-over syndrome,” with a span of behavioral and medical issues. There is also a specific Polar T3 syndrome.

A specific program addressing the Mars issues is the Flashline Mars Arctic Research Station (FMARS). There is currently one such facility in the Arctic, with a second planned. The existing station is on Devon Island in the Arctic sea. It is located on a ridge, overlooking a large impact crater, about a thousand miles from the North Pole. The facility was built in 2000, and is operated by the Mars Society, a non-profit. It is used to define and refine field procedures, test habitat design, study crew performance, and selection criteria. It began operations in 2001. Generally, there is a core crew of ten, with visiting researchers and assistants. A hazard probably not found on Mars is the occasional polar bear, looking for a quick meal. One outside crew member is always armed. Communication to and from the station to external sources is delayed 20 minutes, to simulate the one-way radio/light travel time to Mars. The crew keeps to the somewhat longer Martian Sol day

The Biosphere -2 project, located in the Arizona desert, supports 8

humans for a year in a closed ecosystem.

There is also a Mars Desert Research Station in Utah in the Western United States, operated by the Mars Society. A third station is located near a volcano in Iceland. A fourth station, to be located in Australia, is in the planning stages.

There has been fewer problems on the ISS and other orbiting facilities, mostly because the crew can be in constant contact, and can see home by looking out the window. The crew of a lunar backside surface facility, or heading to Mars will have to be closely monitored for indications of changes in mood and cognition.

Manned Orbiting Lab (MOL)

The Manned Orbiting Lab was a USAF space program circa 1963. It was to be launched into orbit, and then two astronauts could visit it via a Gemini Capsule. Mission duration of up to 40 days were envisioned. The project was a follow on to Dynasoar, a winged space plane. Hardware was built, but the mission was never flown. There were to be seven flights, 5 of them crewed. MOL astronauts in three groups were chosen from Air Force, Navy, and Marine Corps personnel. The project was canceled in 1969. NASA's Skylab mission was the follow-on to a lab in orbit. A Gemini-B Capsule for MOL is at the U.S. Air Force Museum, Dayton, Ohio It has a circular hatch in the heat shield for entering the lab.

MOL would have been launched on an upgraded Titan vehicle. The capsule would dock with the MOL unit in-orbit, and at the end of the mission, would undock, and return to Earth. It was designed to operated in Polar orbit, which would involve a launch from Vandenberg Air Force base in California. The reaction control system for attitude control in orbit was different from the Gemini's OAMS.

A MOL mock-up and a refurbished Gemini capsule (not crewed) were launched from Cape Canaveral on a Titan-IIIc in 1966. The Gemini capsule reentered and was recovered. The MOL released

three satellites, once it achieved orbit. Proposed first crewed flight was to be in 1970, but the program was canceled. NASA offered the military crews the opportunity to transition to the civilian space corps, and the 7 that were eligible did so. All went on to fly on shuttle missions.

The MOL was to be built by Douglas Aircraft. The project was canceled, since it had been demonstrated that un-crewed reconnaissance satellites could spy on our enemies much more cost-effectively.

Skylab

Following the Apollo program, with some spare Saturn's sitting around, the next project was the Skylab space station. This used a Saturn S-IVB upper stage as the structure for the station, launched by a Saturn-V with live first and second stages. The hydrogen fuel tank was re-purposed into the crewed facility, and the hydrogen tank was a waste dump. The payload to orbit was 170,000 pounds. The station was 82 feet long, 56 feet wide, and 36 feet in the other direction. It was quite visible from Earth, when the solar arrays caught the glint of the Sun. Astronauts were carried to the facility in-orbit on three missions in 1973-1974 by Apollo command and service modules launched on Saturn-Ib vehicles. A second Saturn-1b and Apollo stack was kept in standby in case a rescue mission was needed. The lab's orbit was a near-circular 270 miles, with a 50 degree inclination. It was competing for funds and resources with the USAF's MOL project at the time.

The facility had been damaged during launch when the integral micrometeriod shield torn away, taking one of the solar array panels with it. This caused thermal and power problems. During an un-anticipated EVA, the crew rigged a replacement heat shield, and freed the solar panel. The third expedition set a record for days spent in space, at that time, 84 days.

The Industrial design firm for Skylab was headed by famed architect Raymond Lowey. He emphasized habitability and

comfort for the astronaut, He included a wardroom space for meals and relaxation. He also wanted a window to view Earth and space. This has proved to be a great feature on the current ISS. Astronauts who participated in Skylab planning were dubious about the designers' focus on areas such as color schemes and decoration. They vetoed an entertainment center. Skylab food was improved over the earlier lunar mission food.

With a large volume of science data to be managed, the Apollo Guidance Computer (AGC) was not up to the job. The IBM System/4Pi TC-1, a derivative of the IBM S/360 mainframe, and a relative of the subsequent Shuttle's AP-101, was used. This was a radiation-hardened unit, with a 16-bit word, and 16k of memory. It had a custom-designed input-output unit for the lab. It drew 56 watts of electrical power, and weighed 18 pounds. It was built with ttl-technology integrated circuits, and core memory. Ten were built, and two were flown. A standard S/360 mainframe was used to produce code and a simulator was used for verification. An IBM System/360-75 mainframe was used to evaluate the onboard computer's performance in orbit. It could run a simulation at 3.5 times less than real-time.

The 4Pi had 54 different instruction, and supported 32-bit double precision data. Cycle time was 3 microseconds. An add took 3 cycles, and a multiply or divide took 16. It had a 24-bit real-time clock. A simple numeric keyboard was used to communicate with the computer in the lab in orbit, and it could also be loaded via uplink, and by an onboard tape drive.

Liquid waste was not recycled in Skylab as it is on the current ISS. Liquid and solid waste went into the large Oxygen tank in the facility, and was stored. It burned when Skylab re-entered.

The facility provided living and working space for the astronauts, a true shower and toilet, a solar observatory, and fixtures and services for science experiments. Some experimental data including film was brought back with the astronauts. The facility

had two docking ports, and an airlock. When an Apollo capsule was docked, electrical power from the fuel cells in the service module could be used to augment power from the solar arrays.

The first Skylab mission lasted 272 days, not all occupied, followed by an idle period of 394 days, when the computer kept things going. The computer was turned off for 4 years while NASA discussed reboosting Skylab to a higher orbit, or letting it reenter. There was a need to put some mods in the software, but the tools and card decks containing the code had been discarded. This resulted in some 2500 cards being re-punched from code listings. At the end of 4 years, the onboard computer was booted up by ground command, and the updates worked fine.

There were plans to use the Shuttle to repair and reboost Skylab, but the timing did not work out. Skylab was in orbit until 1979, when it reentered the atmosphere, splashing into the Pacific ocean near Perth, Australia.

There was also an entire second Skylab spare. The Skylab 2 / Crew 1 Command Module is at the Naval Aviation Museum, Pensacola, Florida. Skylab 3 / Crew 2 Command Module is at the NASA Visitor Center at Great Lakes Science Center, Cleveland, Ohio. Skylab 4 / Crew 3 Command Module is at the National Air and Space Museum, Washington, D.C. The service modules were jettisoned before the capsules reentered the atmosphere.

The Skylab at the Smithsonian is the functional flight spare unit. The active unit reentered the atmosphere in 1979. Two pieces were recovered and are on display. The museum in Esperance, Western Australia, has some pieces, as does the Alabama Space & Rocket Center Museum.

As follow-ons to Skylab, a number of proposals were presented. Von Braun envisioned a larger station, built from the second stage of the Saturn-V. The second stage would be used for fuel and liquid oxygen on the way to orbit, then vented to space, and an equipment module would be slide into the vented hydrogen tank. Questions about how many Saturn-V's would be available led to the choice of

the S-IVB option.

Skylab-II

Skylab-II was a circa 2013 concept from the Marshall Space Flight Center's Advanced Concepts Office. It would be the same concept as the original Skylab, but used the upper stage hydrogen fuel tank from the Space Launch System then under development. It is to be located at the Earth-Moon L2 point (Lagrange point, a null in the gravity field). Here, it would need minimal orbital adjust to remain at that spot. That particular point is on the other side of the moon, from the Earth. That puts it some 430,000 km from Earth, and 62,800 km from the lunar surface. This is the chosen location for NASA's NGST as well. With the moon between the station and the Earth, a relatively quiet radio environment is achieved. The goal is to support a 4 person crew for 60 days, without a resupply flight. The re-purposed tank would have a diameter of 8.5 meters, larger than the ISS's 4.5 meters. The provided volume would be about 500 cubic meters. Lessons learned from the ongoing ISS mission would be applied to the Skylab-II project. That mission was never flown.

Most of the capsules, Mercury, Gemini, Apollo, Soyuz, were intended more for transportation than habitability. One counter example, though, is the Apollo lunar lander, the LEM. This provided a habitat for two astronauts for their brief stay on the surface. In addition, in the Apollo-13 accident, the LEM provided a available but cramped lifeboat to get back to Earth.

There were 10 launched, of which six landed crew on the lunar surface. The descent stages are still there. On the surface, the LEM had enough power, water, and oxygen for 48 hours on the surface, later extended to 75 hours. The habitable volume was 160 cubic feet.

Space Station Freedom

Space Station Freedom was to be the U.S. follow-on to Skylab in the 1980's. At that time, Russia was working on their third version of the crewed Salyut program, named Kosmos 557. This suffered a failure in orbit and was allowed to reenter. Cost issues for both parties brought the Americans and Russians together on a joint venture, to be called the International Space Station. Many of the concepts and lessons-learned on-orbit were incorporated into the new design.

International Space Station – ISS

In 1993, United State's Space Station Freedom Project, to create the International Space Station, kicked off. On-orbit construction began in 1998, and was completed with a last Shuttle mission in 2011. It is the largest artificial satellite in Earth orbit, and can be seen from the ground with the naked eye. The ISS is a synthesis of several space station modules from the U. S., the Soviets/Russians, the Europeans, and the Japanese. It serves as a laboratory, observatory, and factory in Earth orbit, and is continuously crewed. Part of its mission is to collect information on items in orbit for long duration. It is currently funded through 2024. The assembly began in 1998, with the first module being the Zarya. It is the 11th station sent to orbit. Early stations such as Skylab were not intended for resupply.

The International Space Station is continuously crewed, and orbits the Earth at an altitude of some 250 miles. It is quick, traveling at 17,300 miles per hour. It is also expensive, representing an investment of some $100+ billion dollars by the world community, mostly by the United States and Russia. It is thus the most expensive object ever constructed by mankind. It has been visited by astronauts and cosmonauts from some 15 nations, and by paying tourists. It is at an altitude between 300 and 435 km, and can be seen by the naked eye in the daytime, if you know here to look (there's a NASA ap for that).It has be continuously occupied for more than 16 years, as of this writing. It has been visited by travelers from 17 nations, some for work, some for tourism. It

normally has a crew of 6, and masses 419,500 kg, the largest item in orbit.

Modules

The modules include Zarya (Russian, “dawn”) which is a functional cargo block, and the first to be launched. It was built in Russia, but belongs to the U. S. The Unity module is a passive connecting module, and was brought up on the Shuttle Endeavor. The Quest module houses Russian and US spacesuits for EVA's. It is also used as a sleeping compartment. Zveda (Russian, “star”) is a service module. It provides life support for 6 crew, and sleeping quarters for two. The Destiny module is the primary research lab facility for the U. S. PIRS and Poisk are Russian docking modules. Due to a fault encountered on MIR, all ISS hatches were designed to open inward. Harmony is a node module, providing power and data to the modules connected to it, the European Columbus, and the Japanese Kibo labs. It is also a docking port, supporting the Japanese HTV, Space-X Dragon, and the Orbital-ATK Cygnus. Tranquility is a US module, providing life support functions. All US modules have 6 berthing adapters, to connect to other modules. It is currently connected to the Station core, and hosts the Cupola, a docking port, the Bigelow commercial “Expandable Activity Module,” and Leonardo, a European storage module built in Italy.

The Cupola is an observatory with 7 windows. It was a NASA-ESA Project, built in Turin, Italy. The Rassvet (“dawn”) module is the Russian mini-research module. It was originally a docking module.

Columbus is the European research facility, with provisions for external experiments. Kibo is the Japanese laboratory, the largest module on the ISS. It includes an airlock with a drawer, to deploy Cubesats and other payloads in the space environment.

The current PIRS module is scheduled to be de-orbited. PiRS is a docking compartment; the word means “pier” in Russian. Two

other modules, Zarya, currently owned by NASA, and Rassvet, docked at Zarya, will be replaced.

The Bigelow Expandable Activity Module (BEAM) is a privately owned, inflatable habitat module, developed from NASA technology. It came to the station in 2016, and, so far, has remained inflated. Bigelow Aerospace hopes to use such modules in its own space habitat project. In more than a year in orbit, it has worked well. It is currently used as a storage area. It has been cleared to remain through 2028,

The Nauka (Russian: “science”) module is known as the Multipurpose Laboratory Module The Uzlovoy (Russian “masculine”) module is a ball-shaped docking module that has not yet been launched. It is supposed to be placed on the Earth-facing side of Nauka, and has 6 docking ports.

An ISS model is at the National Air and Space Museum in Washington, D. C. The station is huge, and designed to operate in zero gravity, so a complete full scale model is not feasible. There is a small model at the Goddard Space flight Center Visitor's Center in Greenbelt, Maryland. The best exhibit is at the Marshall Space flight Center, in Huntsville, AL.

ESA

The European Space Agency contributed a laboratory module to the ISS, called *Columbus*. It was built by Thales Alenia Space, in Turin, Italy, and was delivered by the Shuttle Atlantis in 2008. It is controlled from the German Space Operations Center in Munich, Germany. It is a cylindrical module, 23 feet long, with two end cones. There is a berthing mechanism at one end. The module contains ten standard payload racks (ISPR), of which 5 are used by ESA, and 5 by NASA. Unpressurized payload platforms are available at the Columbus external payload facility. The current Columbus project was a downgrading of an earlier ESA project for a crewed space station of their own.

Japan

The Japanese Experiment Module (JEM, named Kibo) is the largest on the station. It came up on three Shuttle missions. There are six major elements, including the pressurized lab, and the exposed facility, and there is a robot arm. The pressurized module is used for press conferences.

Besides the various pressurized modules of the station, there is considerable space outside (no pun intended). The station's Integrated Truss Structure is the backbone. It is nearly 110 meters in length, The main solar arrays and thermal radiators are attached to this truss. The solar cells are of a special design, bifacial. They have two generating surfaces. The solar arrays can be aligned to the Sun, and the other side will receive enough reflected sunlight from Earth to contribute. The station currently has 6 robot arms as well as a mobile crane. The Mobile Servicing System consists of Candarm2, the Mobile Remote Servicer Base, and the Special Purpose Dexterous Manipulator. With the Shuttle-derived latching end effector, the system can latch onto and move large assemblies out the station. In addition, the entire assembly is mounted to the Mobile transporter cart, which rides on rails on the Station's Integrated truss structure.

The Russian NEM-1 and NEM-2 modules are for power for science instruments.

The station also includes a NanoRacks airlock module, which is used to deploy Cubesats from the station. A Cubesat is a small, affordable satellite that can be developed and launched by college, high schools, and even individuals. The specifications were developed by Academia in 1999. The basic structure is a 10 centimeter cube, (volume of 1 liter) weighing less than 1.33 kilograms. This allows multiples of these standardized packages to be launched as secondary payloads on other missions. A Cubesat dispenser has been developed, the Poly-PicoSat Orbital Deployer, P-POD, that holds multiple Cubesats and dispenses them on orbit.

Cubesats sent to the ISS can also be returned to the ground on subsequent return of logistics carriers.

Decommissioning of the ISS

The current ISS will reach end-of-life in the 2020's, and is too big to be allowed to re-enter in one piece. One or more follow-on stations will be built in orbit, re-using some modules from the ISS, and new modules launched from the ground. This is possible due to the modular nature of the ISS, and the lessons-learned during its construction and use. Some of the original modules are end-of-life, and will be re-entered.

The various nations that own parts of the station are responsible for their disposal. The question is, what is the replacement for the ISS. More importantly, what are the follow-ons?

Russia currently has plans to remove some of its ISS modules, and re-purpose them into a new facility, the Orbital Piloted Assembly and Experiment Complex (OPSEK). This is based on an estimated life on-orbit of 30 years, based on the MIR experience.

Besides a permanently crewed station in orbit, we must begin to think of expanding outward. The near time goals are lunar and Martian. These are being addressed. These large projects will benefit from co-operation, not competition. The Deep Space Gateway Project is a joint Russian-US effort, announced in 2017.

Deep Space Habitat

The Deep Space Habitat (DSH) was proposed in 2012, to support human exploration beyond low Earth orbit, as a stepping stone to lunar, asteroid, and Mars missions. It would utilize on-orbit experience with the ISS, and the new Orion capsule. The goal is to have a crew living and working for up to 1 year. An ideal location for the Habitat would be the L1 cislunar Lagrange point, a null in the Earth-Moon gravity field. The advantage of staying at this point is that both the Earth, and the Moon are "downhill" in the gravity field. It is 150 million km from Earth, and 1.5 million KM from the Moon. Strangely, you can orbit a Lagrange point, even

though there's nothing there. The Lagrange point on the opposite side of the Moon from the Earth is where the new James Webb Space Telescope is being placed. The Lagrange points, and there are 5 of them, are solutions in the restricted three body problem of orbital mechanics. The restriction is, one of the 3 body's much be much smaller than the other two. For any two bodies, there are 5 Lagrange points. Problem is, they are not the exact null points that we would like, but are perturbed by all the other bodies in the vicinity. You can trust me, or you can do the math.

The project is in Phase 2 of 3 as of this writing. Besides the Orion capsule for 4, the 60-day mission profile would utilize the Cyrogenic Propulsion System (Liquid hydrogen, liquid oxygen) assembly, a lab module, and an airlock. The MultiMission Space Exploration Vehicle may also be attached. This is a servicing craft for a crew of two, and, most importantly, it includes a toilet.

A 500-day mission is also baselined, requiring the addition of a Multipurpose logistics module. The lessons learned from decades of various space station operations in orbit will be applied, as DSH will be further away from the home planet, and the cost of failures is much higher.

Deep Space Gateway

The Deep Space Gateway (DSG) is a NASA Project for a crewed station in cislunar space. It is intended as a jumping-off point. The Orion crewed vehicle is scheduled to be used for this effort. The Gateway would be located in a polar halo orbit around the Moon. By that, we mean that the spacecraft would be visible to Earth for its entire orbital path. Ion thrusters are proposed for station-keeping. These use electrical power for accelerating various (usually, inert) gasses to high velocity, rather than using fuel and oxidizer. The thrust is generally low, but can be continued for long periods of time.

The Power/Propulsion Module (PPM) will have large solar arrays

for power, 40 kW is baselined. The Cislunar Habitation Module will join the PPM later in orbit, and will provide living and work space. The planned Gateway and Logistics module will join next, providing experiment space and supplies. An airlock module will be added later, to enable EVA operations.

Although we have data on 1 year duration missions close to Earth, the DSG will provide more information on long duration human missions in an environment away from our home planet. All of the ISS partners, US (Nasa), Russia (Roscosmos), Europe (ESA), Japan (JAXA), and Canada (CSA) are participating, and form the nucleus of further human exploration of the solar system.

The project presents daunting challenges in design, testing, delivery, logistics, and operations. The lunar vicinity provides a effective location for expeditions to other places in the solar system. And, it's been a while since we have stepped foot on the Moon. In the mean time, the discovery of water ice at the poles, from remote sensing, is most interesting for a lunar base.

The Gateway will serve, then, as a “enabling infrastructure” for further exploration. It is planned to be placed between the Earth and the Moon, in a null in the gravity field called a libration point. The Gateway will serve as the starting point and the mothership for lunar exploration. Telerobotic rovers on the Moon can be operated from the DSG with ease, although similar operation from Earth suffers from excessive communication time. The DSG offers return to Earth in a matter of days.

This will kick off with Expedition-1, an uncrewed flight of NASA's new Space Launch System (SLS)Vehicle, and Orion Spacecraft. This is scheduled, at the moment, for 2019. Various subsystems for the Orion capsule are now under test at the ISS. NASA estimates a rate of one SLS flight per year is possible, after the second flight. The basic SLS can lift 154,000 pounds to Low Earth orbit, and the advanced vehicle will be capable of lifting crew and 10 metric tons to the lunar vicinity. or more than 40 tons,

non-crewed.

The DSG is designed to use electric propulsion for station-keeping, eliminating the need for thruster fuel, and based on the amount of available sunlight. These will be ion thrusters, that use a monopropellant.

The DSG will result in a one-year crewed mission near the moon, to validate the concept of a flight to Mars. It is not so much the distance to Mars, as the relative orbital positions of the two planets in their solar orbits. The mechanics of the transfer orbit were worked out in 1925 by German scientist Walter Hohmann. In his 1928 book, *A Daring Trip to Mars,* Max Valier shows that one of the most efficient methods of reaching Mars from Earth involves a non-intuitive Venus fly-by. People have been thinking about this for a while.

Lunar Orbital Platform – Gateway

Lunar Orbital Platform-Gateway (LOP-G), is a renaming and restructuring of the Deep Space Gateway, a joint Russian-US effort, and associated missions. This is a step beyond the International Space Station, which will be beyond its useful lifetime in a few years, and will be decommissioned, with some parts being reused, and some re-entered. This will result in a new era of human space exploration, further from Earth. Whether we refer to the emerging facility as a Gateway, a Colony, a settlement, or a habitat, we are talking of a permanently occupied facility. We can consider the habitat to be in orbit (about something), or on the surface of another body, other than Earth. These projects will differ in detail, but will all consist of self-sufficient structures somewhere other than Earth, with an associated logistics train. The Gateway would be continuously crewed, and serves as an outpost from which to explore the lunar and Martian surfaces.

Deep Space Habitat

The Deep Space Habitat (DSH) was proposed in 2012, to support

human exploration beyond low Earth orbit, as a stepping stone to lunar, asteroid, and Mars missions. It would utilize on-orbit experience with the ISS, and the new Orion capsule. The goal is to have a crew living and working for up to 1 year. An ideal location for the Habitat would be the L1 cislunar Lagrange point, a null in the Earth-Moon gravity field. The advantage of staying at this point is that both the Earth, and the Moon are “downhill” in the gravity field. It is 150 million km from Earth, and 1.5 million KM from the Moon. Strangely, you can orbit a Lagrange point, even though there's nothing there. The Lagrange point on the opposite side of the Moon from the Earth is where the new James Webb Space Telescope is being placed. The Lagrange points, and there are 5 of them, are solutions in the restricted three body problem of orbital mechanics. The restriction is, one of the 3 body's much be much smaller than the other two. For any two bodies, there are 5 Lagrange points. Problem is, they are not the exact null points that we would like, but are perturbed by all the other bodies in the vicinity. You can trust me, or you can do the math.

The project is in Phase 2 of 3 as of this writing. Besides the Orion capsule for 4, the 60-day mission profile would utilize the Cyrogenic Propulsion System (Liquid hydrogen, liquid oxygen) assembly, a lab module, and an airlock. The MultiMission Space Exploration Vehicle may also be attached. This is a servicing craft for a crew of two, and, most importantly, it includes a toilet.

A 500-day mission is also baselined, requiring the addition of a Multipurpose logistics module. The lessons learned from decades of various space station operations in orbit will be applied, as DSH will be further away from the home planet, and the cost of failures is much higher.

Salyut

Salyut (“salute”) was the Soviet Union's first space station project. The program ran from 1971 to 1991, and involved 9 units, six of

which were successfully manned. Salyut-1 was the first crewed Space Station. It used a series of onboard computers that were designed and produced by the Scientific Research Institute of Micro-Instruments near Moscow. There were two models with different missions, the Durable Orbital Station (DOS) was civilian, and the Almaz-OPS (Orbital piloted station) was military.

Salyut-1 was the first space station in orbit, launched two years before Skylab. A total of 1,697 occupied days were compiled.

On the first crewed flight to Salyut-1, the crew was unable to dock, due to a failure in the mechanism on their craft. A second mission was successful, and the crew occupied the facility for more than 3 weeks. Unfortunately, the crew was killed while returning, due to a faulty pressurization valve. They were not wearing pressure suits, as the cabin space did not allow that. Salyut 1 was intentionally reentered and destroyed after 175 days in orbit. The replacement unit did not reach orbit, due to a launch vehicle fault. A new mission, launched a few days before Skylab, had a failure that caused the orbit control thrusters to fire continuously, depleting the fuel supply. It reentered the atmosphere and burned.

The evolutionary architecture led to a second docking port being added. The next to last unit was abandoned and reentered due to mold problems onboard. Salyut-7 went to orbit in 1983, and was operational for more than 8 years. It was visited by ten crewed spacecraft, six with long duration crews. The Salyut series led to Mir and the ISS. The heritage of modular design was proven, and continued.

MIR

MIR ("Peace") was a Soviet modular space station, intended for long duration, Earth-orbital mission. It was launched in 1986, had visits from 28 crews, and included other nationalities. It was de-orbited in 2001. It logged the longest duration space mission to that point, more than 437 days in orbit, by two cosmonauts.

The MIR space station used a series of computers, the Argon-16,

the Salyut-4, and the Salyut-5. The Argon-16 was a 16-bit machine, It weighs 70 kilograms, and used 280 watts of power. It entered production in 1974. The Argon-12S flight computer was delivered to the Mir, and took over attitude and orbit control of the 240 ton station. It was in orbit for 3,644 days before reentering the atmosphere.

MIR was designed for a crew of 3, with 6 possible for short periods. The Space Shuttle Atlantis delivered the docking module for MIR. It had seven pressurized modules, and large solar arrays for power. It was assembled in orbit, from various modules, launched separately. There were a total of seven modules, and cargo cranes to assist in maneuvering exterior equipment.

After the basic station was in-orbit, 2 cosmonauts visited in 1986, and powered the station up. On the way back, they visited another orbital outpost, Salyut-7. Later, when the station was occupied, a Kvant module was having trouble docking. An EVA revealed a trash bag in the way. Seems you can't just leave the trash outside the door, in orbit, and have it picked up.

The station used 28 volt dc power, with taps at various locations. The Nickel-cadmium batteries were charged by the large solar panels. Initially, the station had 9 kilowatts available, later expanded to more than 16 kilowatts. MIR had two toilets, which fed into a water recovery system. Collected solid wastes were shipped back to Earth on a resupply vehicle. The facility also had a shower.

MIR was in a near-circular orbit of 354-375 kilometers. Atmospheric drag continually lowered the orbit, and it was reboosted by the resupply vehicles. The station had thrusters for attitude control and pointing. The station maintained an Earth-sea level atmospheric pressure and composition.

There were twenty-eight crews that occupied MIR for various times, each identified as an “Expedition.” These varied in duration from 72 to 437 days. An expedition was 2-3 crew. Visitors were on the station for about a week. In total, 104 persons from 12 nations

visited the orbital facility.

There were two non-cosmonauts visiting Mir. These were Helen Sharman, the first Briton to fly in space, and Japanese TV reporter Toyohiro Akiyama in 1990, as a business trip. Cosmonauts from at least 5 countries visited MIR, as did U.S. Astronaut Jerry Linneger and Shannon Lucid.

During a docking system test in 1977, the docking vehicle collided with the Station's solar array, bounced into one of the modules, and punctured it. This lead to an emergency depressurization of the station. The crew responded quickly and contained the damage. No one was injured. In another incident, in 1997, there was an onboard fire caused by some of the oxygen generating equipment. This filled the facility with toxic fumes. Quick reaction by the crew resulting in containing the damage, and no injuries were reported. At the time, U. S. Astronaut Linnenger was aboard. This has been the most severe fire about an orbiting space station so far. Again, lessons were learned that applied to the planned ISS. Close-out of Mir began in 1998

A resupply craft collided with the solar arrays during a test of the manual docking system. The module was holed, and was leaking the onboard atmosphere to space. Again, quick action on the part of the crew saved the day when they isolated to module by means of an airlock. Unfortunately, access to the module was lost. Later, the onboard crew was able to patch the leak, and open the airlock again.

In the 1990s samples of extremophile molds were taken at Mir. Ninety species of micro-organisms were found , four years after the station's launch. By the time of its decommission in 2001, the number of known different micro-organisms had grown to 140. As space stations get older, the problems with contamination get worse. Molds that develop aboard space stations can produce acids that degrade metal, glass and rubber. The molds in Mir were found growing behind panels and inside air-conditioning equipment. The molds also caused a bad odor, which was often cited as visitors' strongest impressions.

Some biologists were concerned about the mutant fungi being a major microbiological hazard for humans, and reaching Earth in the splashdown, after having been in an isolated environment for 15 years. Similar molds have been found in the ISS.

In 1999, crews arrived to begin decommissioning the station, as the ISS project was ramping up. The station reentered and burned, landing in the South Pacific in March of 2001. The facility had been designed with a 5-year lifetime goal, but lasted 15.

MIR-II refers to a follow-on project, which eventually got incorporated into the ISS. The module used was the Zvexda ("star"). It is the basis for the current station's life support system.

Opsek

The Orbital Piloted Assembly and Experiment Complex is a Russian proposed modular space station in low Earth orbit. This 3rd generation system would consist of some of the Russian segments on the existing ISS, as that facility is decommissioned. The new facility would be targeted to research, and orbital assembly of large modules. If this path is taken, this will represent the 12th Russian Space Station.

Some of the Russian building block modules from the ISS will be removed from that structure, and built into the more compact OPSEK. Theses would include the Poisk Mini-Research Module-2 (MRM-2) and Nauka, the multipurpose laboratory module, which has six docking ports. The latter is the main Russian Laboratory. The Node module would also be reused. It has docking ports for Soyuz and Progress-M. The node module will become the core of the new station. A new Science-Power module will be included for Opsek.

Russian Lunar Orbital Station

The Russian Lunar Orbital Station was a 2007 proposed project for a lunar orbital station, and an eventual surface station. It will be based on MIR and ISS lessons learned. The project may see construction around 2030.

Chinese Lunar Exploration Program

The Chinese see a lunar mission as the next logical step for them in space, as they gain technical and operational experience with their space station. They see commercial potential in Helium-3 mining, and exploitation of other lunar minerals. They have orbited the moon with unmanned craft, and deployed a rover on the surface. They have said that their next endeavor will be a sample return mission.

Tiangong

In Chinese, the name Tiangong means *Heavenly Palace,* quite appropriate for a space station. The goal is to launch a third generation space station, similar to the Russian MIR, by 2020. Tiangong-1 was a 8-ton space laboratory, launched in 2011. The follow-on Tiangong-2 was launched in the Fall of 2016. Tiangong-3 was around 20 tons, and included a cargo resupply vessel. It supports an onboard crew of three, and there were 2 sets of crew that spent time in space. The life of the facility has been extended to beyond 2020, but will not receive any further crews.

China uses the Jiuquan Satellite Launch Center in the Gobi desert of Inner Mongolia. It is one of three Chinese launch facilities, and is suited for large orbital inclination angles. The launch of China's first satellite, and first crewed mission were from this facility.

Tiangong-1, sometimes referred to as a docking target, consists of a propulsion (resource) module and a pressurized module, with a

docking mechanism at either end. The docking port of the experiment section supports automated docking. Its length is 10.5 meters, the diameter is 3.4 meters, and it has a mass of 8,000 kilograms. It was launched in 2011, and is intended for short stays by a crew of three.

The Tiangong-2 space laboratory was launched in 2016. It is a conglomerate of two previous space station projects. The Station is kept supplied by the Tianzhou capsule, with a capacity of 6,500 kg. The Tiangong-3 was cancelled.

A follow-on project is the Chinese Large Modular Space Station, about 1/6th of the ISS in size and weight. The core module Tianhe ("Harmony of Heaven") will be launched around 2019. The station was to be sent into orbit in 2021.

India

ISRO, the Indian Space Research Organization, is considering a space station project of its own, ready around 2030. It had previously announced it would not participate in the ISS.

NASA Lunar Outpost

The NASA Lunar Outpost is an element of the Bush administration (2001-2009) *Vision for Space Exploration.* It was directed by Congress that the facility would be named the *Neil A. Armstrong Lunar Outpost.* The outpost location would be at one of the lunar poles. Since then, remote observations have revealed the presense of water ice in craters at the South Pole The South Pole remains in shadow, and sunlight does not reach the bottom of the craters. Besides the value of in situ water supplies, and the ability to produce hydrogen and oxygen from the water via solar-powered hydrolysis, the ice may contain records of the material of the early solar system. The water is a critical sustainable resource for a crewed lunar base. The Indian Chandrayaan lunar orbiter was

responsible for this discovery.

The outpost will consist of various modules for habitation and laboratory space, a solar array assembly, and a garage for a rover. There will also be a communications facility for the link to Earth. The facility was designed for a crew of four with 7-day visits during deployment, and up to 180 day operational missions.

Commercial Efforts

Space can enable manufacturing facilities for new materials that can't be constructed in a gravity field. Other big moneymakers are orbiting vacation destinations, and in-space manufacturing. This topic isdiscussed in detail in a separate book by the author.

Blue Origin

"...to build space hotels, amusement parks and colonies for 2 or 3 million people who would be in orbit. 'The whole idea is to preserve the earth' he told the newspaper .... The goal was to be able to evacuate humans. The planet would become a park." Jeff Bezos, High School Class valedictorian, 1982, Miami Herald.

Bigelow Aerospace

Bigelow Aerospace is an American space company, headquartered in Las Vegas, NV. It was founded in 1998, and focuses on inflatable modular units, carried to orbit. The company licensed the technology from NASA, and has several Space Act agreements in place. The company has enhanced the TransHab concept.

Several modules have been sent to orbit, including Genesis-I (2006) and Genesis-II (2007). Both are orbital test modules, and remain in orbit but are retired. Both have an expected life of 12 years in orbit, at which point they will reenter the atmosphere and burn. Both Genesis modules were heavily instrumented. Questions remain about their longevity and safety in the space environment.

The Bigelow Expandable Activity Module (BEAM) is in orbit, attached to the ISS since 2016. It was funded by NASA, and was launched on a SpaceX cargo mission. The emphasis of the inflatable modules is proving the radiation protection and debris shielding of the inflatable. It was launched in 2016, and will be evaluated through 2018. At the moment, NASA is looking at the Bigelow design.

Bigelow hopes to put one of their Expandable Bigelow Advanced Station Enhancement (XBASE) modules on the moon by 2021. This is referred to as the B330 Module. Space Complex Alpha is their next-generation commercial space station. At this writing, Bigelow is shut down, due to the global pandemic. The B330 Module is ready for launch, but in storage. It is 45 feet long, and 22 feet in diameter when inflated.

The Bigelow First Base module is intended for lunar habitation for 4 crew.

Bigelow also has plans for its own dual commercial space station, using its modules. These were supposed to launch in 2010 and 2016. An earlier project was titled Commercial Space Station Skywalker. Bigelow relys on commercial services for launch.

Industrial Space Facility

The Industrial Space facility was a private space station proposed in the 1980's, to be built with private funding, by Space Industries, Inc. The founder of the company was Max Faget, who had been Chief of Engineering and Operations at NASA. The concept was to have an un-crewed facility, that could receive temporary life support onboard, during a Shuttle visit. The necessary funding was not forthcoming, and the project never got going. President Reagan had requested $700 million from Congress for the project, but the request was declined.

Russian Commercial Space Stations

The Russians proposed an orbital construction yard in 2008 for payloads too heavy to launch directly from Earth. Pre-fabricated sections would be launched to the facility, and integrated. The facility was called OPSEK – orbital piloted assembly and experiment complex. Modules from the ISS, when decommissioned, would be re-used initially for OPSEK. The station could also be a quarantine stop for astronauts returning from Interplanetary missions. The project has not been implemented.

Another Commercial Space Station project was proposed by Orbital Technologies, a Russian Company. The 2010 design was a single module with a usable volume of about 20 cubic meters. Customers were interesting in pursuing protein crystallization and materials research in orbit. To date, this has not flown in space.

Excalibur-Almaz

Excalibur-Almaz is a private Russian company that has purchased two partially completed Almaz space station hulls.

Almaz “Diamond”was a Russian (Soviet) Military Reconnaissance station, identified as Salyut 2, 3, and 5. The program ran from 1973-1976. These Soyuz craft, were referred to as Orbital Pilot Stations (OPS). This program was similar to the USAF's canceled MOL Project. The Almaz carried a 23mm automatic cannon, for self-defense. It was tested in orbit against a satellite target.

The company estimates they saved $2 billion dollars in development costs. These they plan to use for Space Tourism, and possibly for manufacturing in space. The space cannon were probably not included in the deal. The company is headquartered on the Isle of Man and successfully participated in NASA's Commercial Crew Development Program. The current status of the

company is unknown, but in 2016, their equipment was converted into an education exhibit.

Space Tourism

To develop tourism in space, you need a destination that supports tourists. In space, this is a challenge. Tourists have made short time visits to the ISS. The lunar surface is the next target and Mars is a more complex problem. But NASA and other Space players are looking at it, as well as commercial outfits. As they say in the tourism and hospitality industry, tourist dollars do not need justification by the bean counters. Tourism destinations do not need economic justification. Tourism is for recreational or leisure purposes. Make it available, and they will come. It is the next step in Adventure travel.

Tourism is the business of attracting, accommodating, and entertaining tourists. Tourism is a source of revenue for the entrepreneur, and a source of jobs for the skilled trades needed in the hospitality business. In travel, as in real estate, it's “location, location, location.” No one said the destination needs to be on this planet.

The Space Tourism Society is a 501(c) 3 non-profit, organized in the United States, with chapters in seven other country's. It is focused on the emerging space tourism industry.

Space Island Group

The Space Island Group (www.spaceislandgroup.com) is addressing the manufacture of new materials in space. One product line would be thousands of new metal alloys, that are impossible to manufacture in a gravity field, This has been demonstrated on the International Space Station. The company plans to use a series of orbital modules, that can be leased, by corporations for their own projects.

Space Expedition Corporation

The Space Expedition Company (SXC) was founded in 2008. It did not want to spend money to develop its own rocket, so it arranged to lease one from XCOR. SXC was acquired by XCOR in 2014. The company was renamed XCOR Space Expeditions. It offers suborbital flights from the Mojave Spaceport in Arizona, and California. They were planning on a spaceport facility on the Caribbean island of Curaçao.

The Orbital Mission Explorers Circle is a program that lets interested individuals reserve seats on future flights. Sergey Brin, of Google, was a founding member. A reservation is $5 million. The Circle is a fraternity (and sorority) of future private space explorers. Founding Explorers, of which there are six positions, have priority access.

Another announced program will offer a spacewalk option. It would allow about 1.5 hours outside the ISS. More training is required for this option.

Thinking big, there is also a lunar option, This is estimated to cost $100 million per seat, but provides a circumnavigation of Earth's first satellite. This would use a Soyuz capsule, which will dock in orbit with a service/propulsion module (like Apollo did), This would be about a 10-day mission.

The obvious next step is a lunar drive-by, or landing.

Space-X

Space-X hopes to send their privately crewed Dragon spacecraft around the moon, by 2022. This would carry two tourists. Space-X has been accepting deposits for this activity.

SpaceX has said it views space tourism as "an important step

toward enabling access for everyday people who dream of traveling to space." Japanese billionaire Yusaku Maezawa will be SpaceX's first space tourist. He has a ticket for a slingshot trip around the Moon as early as 2023. He's planning to take six to eight artists with him on the mission free of charge.

"I want to share this experience and things with as many people as possible," Maezawa said at a news conference. "So, I choose to go to the Moon with artists."

Musk is currently saying the company no longer has plans to certify the Falcon Heavy for human spaceflight.

Playboy Enterprises

Playboy has proposed an orbital "space club", in conjunction with Virgin Galactic. Their plans include a restaurant and a zero gravity dance club. This was discussed in the March, 2012 issue of their magazine. The concept is a ferris-wheel shape, like the original Von Braun Space Station.

There are using a cruise ship model, with bar, restaurant, dance club, casino, and waitresses in jetpacks. An arrangement is in place with Virgin Galactic to use their SpaceShipTwo, for around $200,000 for transportation,

Is this real, or just a publicity stunt? Well, there is nothing in the laws of physics to prevent it – it will only take money. I wonder about the effects of alcohol in Zero-G?

Asgardia, another approach

The Space Kingdom of Asgardia is a proposed space-based nation-state, announced in 2016, by Igor Ashurbeyl. The Outer Space Treaty currently governs all extra-terrestrial activities by governments, NGO's and commercial entities. The treaty was put

in place in 1967. As of July 2017, 107 countries are signatories, with 23 signed, but not finished ratification. The treaty is an attempt to define a legal framework for Space Law, as was done for the Law of the Sea previously. No government can claim a moon or a planet for its sole use. Space objects that are launched by signatories remain the property of the launch entity. Accordingly, the owner is responsible for damages caused by that object. The government is responsible for the activities of NGO's under their jurisdiction.

Anyone can apply for Asgardia citizen, and more than ½ million have. The entity wishes to apply for U.N. Membership, although it has no terrestrial territory. I The project is currently privately funded, by founder Igor Ashurbeyli but is seeking crowdfunding.

The Cygnus spacecraft that launched Asgardia-1 into space released it and two other satellites on 12 November 2017.

Design Studies for Colonies

People have been thinking about habitats in space for a long time. Hales book, “the Brick Moon,” in 1869 applied 1860's thinking and technology to the problem, and came up with a hand-waving launch process, but a viable construction – essentially heat-resistant tiles.

One hundred and twenty-eight Nations have signed the UN Treaty that states no country can “own” part of a celestial off-Earth body. It should be interesting to see how this plays out, after commercial entities begin to mine the moon and asteroids for profit.

The commercial company Blue Origin is actively developing a lunar lander. The company is owned by Jeff Bezos, who also owns Amazon, and the Washington Post. They are also developing their own heavy lift rocket, the New Glenn. Boeing is looking as a cis-lunar habitat. Lockheed Martin and United Launch Alliance are focusing on Mars.

Orbiting Hotels and Sports Centers

The dynamics of an artificial gravity swimming pool have been studied, and such a facility would provide a unique addition to an orbiting hotel. Variation of Earth-based sports will have 0-G equivalents, but a little gravity allows easier transition.

In zero G, if we had a pool module with an airlock, we would find the water, due to surface tension, formed a large sphere. There would be a lack of buoyancy, but normal swimming motions, in a reaction against the water, would still be effective. One issue is, you would not spontaneously float to the surface.

Further along, we could envision vacation destinations on the lunar surface. Here, we operate in about 1/6 of the gravity we are used to, and the water will stay in the designated pool. Where does the water come from? There is thought to be large amounts of water ice in craters at the lunar poles. This is being sought, because it can be converted to hydrogen and oxygen (rocket fuel) by solar electrolysis. We can just define the ”rocket fuel holding tank” as the swimming pool.

Besides defining variations of Earth-sport, we can implement a new one in Lunar gravity – flying. Since our weight will be 1/6, this is quite feasible with strap-on wings. It will take a bit of getting used to, but look forward to it at the Lunar Icarus Center.

Another activity that can evolve in lower-G / zero-G is performance art. Earth-developed scenarios could be modified for the Zero-G environment. To date, almost all space voyagers have been scientific/technical folks. As Space Tourism opens this to “ordinary people,” entirely new things will evolve, that we haven't thought of yet.

From NASA studies, after 2 days in weightlessness, the spine straightens out, and you grow about 3% in height. This is an issue for space suits. Weightless posture is different. Adapting back to Earth-normal gravity takes a few days, as well.

Communications with the ground is no problem, either direct or

through one of the Tracking and Data Relay Satellites. The orbiting facility can implement a cell phone hot spot and wifi. It will be expensive to use. So, what area code do we use for Earth orbit?

Should we take our pets with us? Cats have done well in adapting to Zero-G, from flights on the Vomit Comet. A concern for all manner of pets is waste disposal. If the cost of your pet's flight is about the same as yours, Little fluffy will probably remain on the ground.

Solar flares, Coronal Mass Ejections can also endanger the crew and guests. They then have to gather in their equivalent of a tornado shelter. A series of sentinel satellites track these events originating in the Sun, and provide ample warning time. To date, no evacuation of the International Space Station has been necessary. The Crew normally is exposed to the same radiation in 1 day, which a person one Earth would get in a year. This should not be an issue for short-stay guests, but could limit the working duration of staff.

Staff will need training beyond what the tourists get, because they will be living in the facility, and will, like ships' stewards, be responsible for safety. There are also the issues of business insurance, and safety certification. As with any totally new adventure, some of this will initially be solved with guesswork.

A Russian Company, Orbital Technologies, was planning for a luxury hotel in orbit in 2010, as a destination. Why not a luxury facility? Would you pay a million for a trip to a Motel-6 in orbit? The facility will have seven guest rooms, and is projected to be at an orbit of 220 miles. First launch was to be in 2016, but that never happened. Status of the project is unknown.

The Spanish Company, Galactic Suite Design, is developing concepts for the interior of space habitats. They had a project in 2007 to design an orbiting station.

ESA has plans for a lunar resort called the Moon Village. The infrastructure would be launched to the lunar surface and

constructed by telerobotics. Besides tourism, the established base could support lunar surface research and manufacturing. The projected date for this project is 2030. It is projected that this facility will be at the lunar poles. Theme Parks, we need lunar theme parks. der Space Colonization

As of this writing, the space activities have gone from an Astronaut on a ballistic trajectory, to a fully crewed multi-year space station, to plans for the LOP-G, lunar bases, and Mars missions.

The next steps have been known for decades – permanent habitation on another planet. That, and human exploration of the outer planets will take our attention for decades into the future. After that, the solar system won't be able to hold us. This will require technologies that have yet to be developed. And, throughout history, humans were explorers. They always wondered "what was over there?"

In the shorter term, space Colonization will take our best efforts for a long time. It is obvious that the colonists will need to utilize in-situ materials and energy sources. Space is hostile to life. That's why our planet is important to us.

Why are the expense and effort? For one thing, it might help to ensure the survival of our civilization. If there was a global disaster, having friends in other places might help us recover. That could include direct assistance, and additional resources.

Space is full of vast resources for us to utilize. We just need the technology to do it. We are not going to be able to lift all the materials we need from the Earth's surface, so it will be important to develop the technologies for lunar and asteroid mining and processing. Many Earth resources are non-renewable, but could be replaced with off-planet resources. Let's plan from the beginning not to trash other planets. Resources that can't be used, or are radioactive or toxic, can be sent on a one-way trip to the Sun.

Orbital Development Corporation is proposing a project to exploit the near-Earth asteroid Eros. It's some 20 miles long, with an

estimated mass of nearly 80 trillion tons (10^{12}). Thanks to the NEAR Shoemaker spacecraft, much of its composition is known, and includes iron, aluminum, silicon, and magnesium. It is likely that rare-earth metals are also present. It is proposed to build a habitat at one point on the spin axis, with a shipyard at the other. Mr. Gregory W. Nemitz claims ownership of the asteroid, which has been contested in Federal Court. He sent NASA a parking bill for the NEAR spacecraft on the surface. We'll see how this all works out, but it is precedent-setting, and needs to be decided before large-scale commercial exploitation of space resources is begun.

References

Abitzsch, Sven “Prospects of Space Tourism,” 1996, Proceedings at the 9th European Aerospace Congress, avail: http://www.spacefuture.com/archive/prospects_of_space_tourism.shtml.

Aldrin, Buzz *No Dream Is Too High, Life Lessons From a Man Who Walked on the Moon*, National Geographic, 2016, ISBN-9781426216497.

Anderson, Eric C., Piven, Joshua *The Space Tourist's Handbook*, 2005 Quirk Books, ISBN-1594740666.

Baker, David *The History of Manned Space Flight*, 1982, Crown Publishers, ISBN-051754377X.

Bell, S. S.(ed), McCoy, Earl D. (ed), Mushinsky, H.R. (Ed) *Habitat Structure: The physical arrangement of objects in space*, 1990, ISBN-0412322706.

Berinstein, Paula, Terenzi, Dr. Fiorella *Making Space Happen: Private Space Ventures and the Visionaries Behind Them*, 2002, ASIN-B00719IM12.

Buckley, James *Home Address: ISS: International Space Station,* Smithsonian, Sep 1, 2015.

Chladek, Jay *Outposts on the Frontier: A Fifty-Year History of Space Stations (Outward Odyssey: A People's History of Spaceflight*, 2017 U. Nebraska Press, ISBN-0803222920.

Choi, Charles Q. “In Race for Private Space Stations, It's U.S. Versus Russia,” Nov. 12, 2010. Space.com, avail: https://www.space.com/9518-race-private-space-stations-russia.html.

Cichana, Timothy; O'Dellb, Sean; Richeyc, Danielle; Baileyd,Stephen A.; Burche, Adam "MARS BASE CAMP UPDATES AND NEW CONCEPTS," 2017, IAC-17, 68th International Astronautical Congress (IAC).

Collins, Patrick "The Future of Lunar Tourism," avail: http://www.spacefuture.com/archive/the_future_of_lunar_tourism.shtml

Collins, P. Fukuoka, T.; Nishimura,T., "Zero-Gravity Sports Centers, Engineering Construction & Operations in Space 4," 1994, ASCE, Vol 1, pp 504-13.

Compton, William David *Living and Working in Space: The NASA History of Skylab*, Dover, 2011, ISBN-0486482189.

Eckhart, Peter *The Lunar Base Handbook,* 1999, 1st ed, McGraw-Hill Primis Custom Publishing, ASIN-B01A1MSBRK.

Feldman, Heather *Dennis Tito: The First Space Tourist* (Space Firsts), 2003, ISBN-0823962490.

Griffin, Brand "Skylab II: Making a Deep Space Habitat from a Space Launch System Propellant Tank, "March 27, 2013 Future In-Space Operations Colloquium, Future In-Space Operations Working Group. Avail: http://spirit.as.utexas.edu/~fiso/telecon13-15/Griffin_3-27-13

Hale, Edward Everett *The Brick Moon*, 2021 (reprint) ISBN -148128326X

Heppenheimer, T. A. *Colonies in Space, A Comprehensive and Factual Account of the Prospects for Human Colonization of Space*, 1977, ISBN-0-446-81-581-0.

Hitt, David *Homesteading Space: The Skylab Story,* 2008,

University of Nebraska Press, ASIN-B003NHSBNU

Launius, Roger D. *Space Stations: Base Camps to the Stars*, 2003, Smithsonian Books, ISBN-1588341208.

Ley, Willy *Space Stations: Adventures in Space*, 1958, Guild Press, ASIN-B000LB5OMC.

Mendell, Wendell W. *Lunar bases and Space Activities of the 21st century,* 1985, Lunar and Planetary Institute, ISBN 0-942862-02-3.

Merrow, Mark *A Lunar Space Station: NASA's Study to Design a Lunar Space Station in Support of a Manned Moon Base,* 2015, alc Books, ASIN-B014LQ177S.

NASA, *NASA Space Technology Report: Lunar and Planetary Bases, Habitats, and Colonies, Special Bibliography Including Mars Settlements, Materials, Life Support, Logistics, Robotic Systems,* ASIN-B00CLX44E2.

NASA, *Inside the International Space Station (ISS): NASA International Space Station Familiarization Astronaut Training Manual - Comprehensive Review of ISS Systems*, 2011, ASIN-B006O403MG.

NASA, *Reference Guide to the International Space Station*, 2014, ASIN-B00M3K6LP8.

NASA, *Mir Space Station NASA Astronaut Training Manual - Complete Details of Russian Station Onboard Systems, History, Operations Profile, EVA System, Payloads, Progress, Soyuz, Salyut*, 2012, ASIN-B008RIC140.

NASA, *NASA Space Technology Report: Deep Space Habitat Concept of Operations for Transit Mission Phases - Mars, Phobos / Deimos, Near Earth Asteroid, Habitats, Crew Systems,* 2013, ASIN-B00EG4N3E6.

NASA, *NASA Space Technology Report: Deep Space Habitat Concept of Operations for Transit Mission Phases - Mars, Phobos / Deimos, Near Earth Asteroid, Habitats, Crew Systems,* 2013, ASIN-B00EG4N3E6.

Rohrabacher, Dana *Space Tourism: Hearing Before the Committee on Science, U.S. House of Representatives,* Oct 2003, ISBN-0756727464.

Seedhouse, Erik *Bigelow Aerospace: Colonizing Space One Module at a Time*, 2015, Springer, ISBN-3319051962.

Seedhouse, Erik *Tourists in Space: A Practical Guide*, Springer Praxis Books, 2014, ISBN- 3319050370.

Seedhouse, Erik *Lunar Outpost: The Challenges of Establishing a Human Settlement on the Moon,* 2008, Springer, ISBN-0387097465.

Smitherman, David *Habitat Concepts for Deep Space Exploration,* 2014, NASA, ASIN-B01ED7JF10.

Thorpe, Andrew M. *The Commercial Space Station: Methods and Markets,* 2007, ISBN-978-1434327604.

Tsiolkovsky, K Beyond the Planet Earth, 1900, reprinted 1960, Pergamon Press, ASIN-B0000CKO3P.

Van Pelt, Michel *Space Tourism: Adventures in Earth Orbit and Beyond*, 2010, ISBN-1441923144.

Zubrin, Robert, *Mars on Earth, The Adventures of Space Pioneers in the High Arctic* 2003, ISBN-1-58542-255-X.

Glossary of terms

AFB – Air Force base
Apogee – furthest point in the orbit from the Earth.
ASCE – American Society of Civil Engineers.
ASIN – Amazon Standard Inventory Number
BEAM – Bigelow Expandable Activity Module
Bean Counter – slang, accountant.
BEO – beyond Earth orbit.
BFR – (SpaceX) Big Falcon rocket.
Blooster – balloon-based launch vehicle
C3PO – NASA Commercial Crew and Cargo Program Office
CME – (solar) Coronal Mass Ejection
ConOps – concept of operations
CSF – Commercial Spaceflight Foundation
CSS – Chinese Space Station
CST – (U.S. Office of) Commercial Space Transportation.
C&W – caution and warning
Cyrogenic – pertaining to very low temperatures.
DRM – design reference mission.
ECLSS – Environmental Control & Life Support System.
EELV – Evolved Expendable Launch Vehicle (U. S.)
ESA – European Space Agency
ETR – Eastern Test Range, Cape Canaveral, FL
EVA – extra-vehicular activity
FAA – Federal Aviation Administration, oversees spaceflight launch.
GEO – geostationary orbit
GPS – global positioning system
GSFC – NASA Goddard Space Flight Center, Greenbelt, MD.
HITL – Human in the loop.
HSIR – human systems integration requirements.
IISL – international institute of space law.
ISBN – international standard book number.
ISPR – International Standard Payload Rack.
ISS – International Space Station

JAXA – Japanese Space Agency
JSC – Johnson Space Center, Houston, Texas.
Kármán line – international definition of the beginning of Space. 100 Km above the surface.
KSC – NASA Kennedy Space Center, launch site, Florida.
LEO – low Earth orbit
LSSPO – (NASA) Lunar Surface Systems Project Office, JSC.
MIR – Russian Space Station.
MOL – Manned Orbiting Lab
MPCV – multi Purpose Crew Vehicle
NASA - National Aeronautics and Space Administration.
NEO – near Earth object.
NGO – Non-governmental organization, commercial or non-profit.
NGST – NASA's Next Generation Space Telescope
NHV – net habitable volume
OAMS – Orbital attitude maintenance system.
Orbitel – orbital hotel
NOAA – (U.S.) National Oceanographic and Atmospheric Administration.
Perigee – closest point in the orbit from the Earth.
PSF – Personal Spaceflight Federation
RF – radio frequency.
ROSCOSMOS – Russian Space Agency
RPM – revolutions per minute.
RPOD – Rendezvous, Proximity Operations, Docking
SHFE – space human factors engineering
SI – System International – the metric system.
Soyuz – Soviet/Russian crewed capsule.
SXC – Space Expedition Corporation
SPACE Act, Spurring Private Aerospace Competitiveness and Entrepreneurship, 2015
STS – Space Transportation System (Shuttle)
SXC – Space Expedition Corporation.
TDRS – Tracking and Data Relay Satellites.
Terraforming – modifying the ambient environment to be Earth-like.
TransHab – NASA concept in 1990; canceled. Influenced Bigelow

TRL – Technology Readiness level
ULA – United Launch Alliance
Vomit Comet – an aircraft flying parabolic flight paths, giving periodic weightlessness.
VSS – Virgin (Galactic) Space ship.
V&V – verification and validation.
Zombie-Sat – dead satellite, in orbit.

Resources

www.nasa.gov

https://history.nasa.gov/

https://history.nasa.gov/tindex.html#5

bigelowaerospace.com

Wikipedia, various.

If you enjoyed this book, you might also be interested in some of these.

16-bit Microprocessors, History and Architecture, 2013 PRRB Publishing, ISBN-1520210922.

4- and 8-bit Microprocessors, Architecture and History, 2013, PRRB Publishing, ISBN-152021572X,

Apollo's Computers, 2014, PRRB Publishing, ISBN-1520215800.
The Architecture and Applications of the ARM Microprocessors, 2013, PRRB Publishing, ISBN-1520215843.

Earth Rovers: for Exploration and Environmental Monitoring, 2014, PRRB Publishing ISBN-152021586X.

Embedded Computer Systems, Volume 1, Introduction and Architecture, 2013, PRRB Publishing, ISBN-1520215959.

The History of Spacecraft Computers from the V-2 to the Space Station, 2013, PRRB Publishing, ISBN-1520216181.

Floating Point Computation, 2013, PRRB Publishing, ISBN-152021619X.

Architecture of Massively Parallel Microprocessor Systems, 2011, PRRB Publishing, ISBN-1520250061.

Multicore Computer Architecture, 2014, PRRB Publishing, ISBN-1520241372.

Personal Robots, 2014, PRRB Publishing, ISBN-1520216254.

RISC Microprocessors, History and Overview, 2013, PRRB Publishing, ISBN-1520216289.

Robots and Telerobots in Space Applications, 2011, PRRB Publishing, ISBN-1520210361.

The Saturn Rocket and the Pegasus Missions, 1965, 2013, PRRB Publishing, ISBN-1520209916.

Visiting the NASA Centers, and Locations of Historic Rockets & Spacecraft, 2017, PRRB Publishing, ISBN-1549651205.

Microprocessors in Space, 2011, PRRB Publishing, SBN-1520216343.

Computer Virtualization and the Cloud, 2013, PRRB Publishing, ISBN-152021636X.

What's the Worst That Could Happen? Bad Assumptions, Ignorance, Failures and Screw-ups in Engineering Projects, 2014, PRRB Publishing, ISBN-1520207166.

Computer Architecture & Programming of the Intel x86 Family, 2013, PRRB Publishing, ISBN-1520263724.

he Hardware and Software Architecture of the Transputer, 2011,PRRB Publishing, ISBN-152020681X.

Mainframes, Computing on Big Iron, 2015, PRRB Publishing, ISBN- 1520216459.

Spacecraft Control Centers, 2015, PRRB Publishing, ISBN-1520200617.

Embedded in Space, 2015, PRRB Publishing, ISBN-1520215916.
A Practitioner's Guide to RISC Microprocessor Architecture, Wiley-Interscience, 1996, ISBN-0471130184.

Cubesat Engineering, PRRB Publishing, 2017, ISBN-1520754019.

Cubesat Operations, PRRB Publishing, 2017, ISBN-152076717X.
Interplanetary Cubesats, PRRB Publishing, 2017, ISBN-1520766173 .

Cubesat Constellations, Clusters, and Swarms, PRRB Publishing, 2017, ISBN-1520767544.

Graphics Processing Units, an overview, 2017, PRRB Publishing, ISBN-1520879695.

Intel Embedded and the Arduino-101, 2017, PRRB Publishing, ISBN-1520879296.

Orbital Debris, the problem and the mitigation, 2018, PRRB Publishing, ISBN-1980466483.

Manufacturing in Space, 2018, PRRB Publishing, ISBN-1977076041.

NASA's Ships and Planes, 2018, PRRB Publishing, ISBN-1977076823.

Space Tourism, 2018, PRRB Publishing, ISBN-1977073506.

STEM – Data Storage and Communications, 2018, PRRB Publishing, ISBN-1977073115.

In-Space Robotic Repair and Servicing, 2018, PRRB Publishing, ISBN-1980478236.

Introducing Weather in the pre-K to 12 Curricula, A Resource Guide for Educators, 2017, PRRB Publishing, ISBN-1980638241.

Introducing Astronomy in the pre-K to 12 Curricula, A Resource Guide for Educators, 2017, PRRB Publishing, ISBN-198104065X.

Also available in a Brazilian Portuguese edition, ISBN-

1983106127.
Deep Space Gateways, the Moon and Beyond, 2017, PRRB Publishing, ISBN-1973465701.

Exploration of the Gas Giants, Space Missions to Jupiter, Saturn, Uranus, and Neptune, PRRB Publishing, 2018, ISBN-9781717814500.

Crewed Spacecraft, 2017, PRRB Publishing, ISBN-1549992406.
Rocketplanes to Space, 2017, PRRB Publishing, ISBN-1549992589.

Crewed Space Stations, 2017, PRRB Publishing, ISBN-1549992228.

Enviro-bots for STEM: Using Robotics in the pre-K to 12 Curricula, A Resource Guide for Educators, 2017, PRRB Publishing, ISBN-1549656619.

STEM-Sat, Using Cubesats in the pre-K to 12 Curricula, A Resource Guide for Educators, 2017, ISBN-1549656376.

Embedded GPU's, 2018, PRRB Publishing, ISBN- 1980476497.

Mobile Cloud Robotics, 2018, PRRB Publishing, ISBN-1980488088.

Extreme Environment Embedded Systems, 2017, PRRB Publishing, ISBN-1520215967.

H. What's the Worst, Volume-2, 2018, PRRB Publishing, ISBN-1981005579.

Spaceports, 2018, PRRB Publishing, ISBN-1981022287.

Space Launch Vehicles, 2018, ISBN-1983071773.

Mars, 2018, PRRB Publishing, ISBN-1983116902.

X-86, 40th Anniversary ed, 2018, ISBN-1983189405.

Lunar Orbital Platform-Gateway, 2018, PRRB Publishing, ISBN-1980498628.

Space Weather, 2018, ISBN-1723904023.

STEM-Engineering Process, 2017, ISBN-1983196517.

Space Telescopes, 2018, PRRB Publishing, ISBN-1728728568.

Exoplanets, 2018, PRRB Publishing, ISBN-9781731385055.

Planetary Defense, 2018, PRRB Publishing, ISBN-9781731001207.

Exploration of the Asteroid Belt, 2018, PRRB Publishing, ISBN-1731049846.

Terraforming, 2018, PRRB Publishing, ISBN-1790308100.

Martian Railroad, 2019, PRRB Publishing, ISBN-1794488243.

Exoplanets, 2019, PRRB Publishing, ISBN-1731385056.

Exploiting the Moon, 2019, PRRB Publishing, ISBN-1091057850.

RISC-V, an Open Source Solution for Space Flight Computers, 2019, PRRB Publishing, ISBN-1796434388.

Arm in Space, 2019, PRRB Publishing, ISBN-9781099789137.
Extraterrestrial Life, 2019, PRRB Publishing, ISBN-978-1072072188.

Submarine Launched Ballistic Missiles, 2019, ISBN-978-

1088954904.

Space Command, Military in Space, 2019, PRRB Publishing, ISBN-978-1693005398.

CubeRovers, A Synergy of Technologys, 2020, PRRB Publishing, ISBN-979-8651773138.

Robotic Exploration of the Icy moons of the Gas Giants. 2020, PRRB Publishing, ISBN- 979-8621431006

Hacking Cubesats, 2020, PRRB Publishing, ISBN-979-8623458964.

History & Future of Cubesats, PRRB Publishing, ISBN-979-8649179386.

Hacking Cubesats, Cybersecurity in Space, 2020, PRRB Publishing, ISBN-979-8623458964.

Powerships, Powerbarges, Floating Wind Farms: electricity when and where you need it, 2021, PRRB Publishing, ISBN-979-8716199477.

Hospital Ships, Trains, and Aircraft, 2020, PRRB Publishing, ISBN-979-8642944349.